TITLE

# SIMULATION OF ELECTRO-OPTICAL CONNECTIONS THAT TAKES SPATIAL DIRECTION INTO CONSIDERATION

## BACKGROUND OF THE INVENTION

### Field of the Invention

The invention is directed to a method for determining the transmission behavior of electro-optical connections, particularly connections in the inside of devices.

### Description of the Related Art

The article, "Verhaltensbeschreibung für die Modellierung opto-elektronischer Systeme" by J. Becker, J. Haase and P. Schwarz, pp. 83-92 of the Conference Volume of the GMM-ITG-GI Workshop "Multi-Nature Systems" on 11 February 1999 in Jena, herein incorporated by reference, discloses that a modelling of electro-optical transmission links can take place with network simulators known for electrical networks. A simple preferred model in which the entire radiant power generated at an output of an electro-optical transducer or, respectively, received, is simulated by a single node of the model. An as yet unpublished proposal is also mentioned at the bottom of page 86 in which a plurality of terminals are provided at the optical side with which different optical wavelengths are separately modelled. This version is of interest for wavelength-division multiplex methods that are utilized in the field of telecommunications.

The article by Th. Bierhoff et al., "An Approach to Model Wave Propagation in Highly Multimodal Optical Waveguides with Rough Surfaces" in Proc. X. Int. Symp. on Theoret. Electr. Eng., Magdeburg 1999, pp. 515-520, herein incorporated by reference, is cited for modelling transmission properties of optical multimode waveguides.

## SUMMARY OF THE INVENTION

An object of the invention is to provide a method with which the transition into and out of the optical waveguide can be simulated, and a complex model of the optical waveguide or, respectively, of the entire optical transmission path can be utilized.

The invention is based on the fact that a division of the radiation into respectively predetermined spatial directions means a significant improvement of the model with respect to the transmitter and receiver. In this scheme, the improved model of the optical transmission link no longer represents a simple transmission quadripole (in the form of coupled dipoles) but a multi-pole with a transmission matrix. The example discussed below shows how model parameters are defined.

The method provides for simulating the transmission behavior of opto-electronic connections in which the transmitter or the receiver (or both) is represented by at least two optical outputs (transmitter) or, respectively, inputs (receiver), and the optical line is represented by corresponding multi-poles, by which the direction and the spatial distribution of the emitted (transmitter) or, respectively, received (receiver) radiation is taken into consideration.

Furthermore, features and advantages of the invention derive from the following description that, combined with the attached drawings, explains the invention on the basis of an exemplary embodiment.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagrams showing the structure of an arrangement to be simulated;

Figure 2a is a pictorial diagram showing the preferred model for the transmitter;

Figure 2b is a pictorial diagram showing the preferred model for the receiver;

Figure 3 is a schematic diagram of an electrical network that simulates the structure according to Figure 1;

Figure 4a is a schematic diagram showing an arrangement for determining the properties of the transmitter; and

Figure 4b is a schematic diagram showing an arrangement for determining the properties of the receiver.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates, in a two-dimensional manner, an arrangement to be simulated. An electro-optical transmitter 10 has an electrical terminal 11. Vertically emitting laser diodes are preferably employed here, as widely known under the abbreviation VCSEL (vertical-cavity surface-emitting laser diodes). However, other optical sources (for example, edge emitters, LEDs, etc.) can also be utilized and modeled here.

A ray beam, illustrated by the rays S1, S 2, S3 and S4, is emitted from this transmitter and is incident onto the input face 22 of a light conductor 20. The rays entering into the light conductor (illustrated by lines) are reflected by total reflection at the edge based on the principle of the light conductor and are potentially dispersed by roughness and emerge from the exit face 23 at the end of the light conductor; an input beam can also lead to a plurality of output beams in the case of light dispersion. They are then incident onto a receiver 30 that in turn produces an output 32 that corresponds to the optical powers incident onto the receiver 30 in the segments E1, E2, E3, ... En-1, En.

It is already indicated in Figure 1 that the receiver is envisioned to be composed of individual elements for the purpose of the invention. Since Figure 1 is a two-dimensional projection, Figures 2a & 2b present the actual three-dimensional transmitter and receiver employed. In Figure 2b, the receiver 30 in the model actually employed is a surface that is divided into sub-surfaces. This division is preferably a tiling with quadratic grid 34, as indicated in a perspective view in Figure 2b.

Although the receiver is preferably modeled by a planar tiling, the transmitter - as indicated in Figure 1 and in Figure 2a - preferably has a division in which the ray beams S1-S4 emanate from a common center.

This modeling corresponds to the fact that the transmitters presently preferred have an emission face that is small in relationship to the diameter of the light conductor, which is envisioned as punctiform in the model. However, surface

radiators (with planar and arbitrarily curved surfaces) in which the individual rays do not proceed from a common point can also be modeled with the method.

The receivers, in contrast, have a significantly larger reception face 33 because the sensitivity increases with the area. This area is optimally only slightly larger than the exit face of the light conductor. Since the receiver is preferably a planar element, it is positioned immediately against the exit face; the spacing is shown disproportionately large in Figure 1 for the sake of clarity.

Figure 3 shows an electrical equivalent circuit diagram that corresponds to the simplest arrangement. This electrical network is divided into three regions A, B, and C, where A corresponds to the transmitter, B corresponds to the line and C corresponds to the receiver.

Input posts I that correspond to the electrical connection of the transmitter are present in the region A. They lead to the electrical model of a transmission diode SD that simulates the electrical properties at the input I, particularly the impedance, in a known way. An exact presentation can be derived from textbooks about electrical networks and the data sheets of the respective diodes. The current flowing through the diode SD controls the voltage sources U1 and U2 according to control characteristics. This is shown in Figure 3 with the two arrows from the diode SD to the voltage sources U1 and U2. The optical transmission intensity is represented by the voltage at the voltage sources U1 and U2. As a rule, more than two voltage sources will be present; however, it is also possible to work with only two when the emitted optical power is to be described in only two spatial regions.

The input face of the light conductor modeled by the region B is divided into two regions in the model, these being representative of the input impedances R11 and R12. These particularly serve the purpose of modeling the transmission losses upon entry into the light conductor.

Analogously, output current sources S21 and S22 are provided for which current is defined via the coupling factors K11, K12, K21 and K22 of the currents by the input impedances R11 and R12. The coupling factors are preferably defined by beam tracking.

The opto-electrical receiver is modeled in region C of Figure 3. The currents from the current sources S21 and S22 are impressed at the input posts (pairs), two input posts are shown in Figure 3, but a plurality of input posts may be provided in a practical application corresponding to the selected tiling. These currents generate signals in the receivers E1 and E2 that are supplied into a photo-element PE by the indicated arrows. The photo-element is usually a photodiode whose properties at the electrical side are modeled with a corresponding network in a known way. An electrical signal thus arises at the electrical output O.

The transfer function of the entire transmission link can now be defined using widely known analysis and simulation. In addition, how current sources can be potentially replaced by voltage sources and how the parameters are then transformed are also adequately known from the theory of the electrical networks. It is also known how, given measured sub-transfer factors - or calculated sub-transfer factors in the case of beam tracking, the sub-transfer functions preferably presented by matrices are defined and how an overall transfer function can be calculated from them. Digital computers may preferably be used, particularly with the software packet SPICE established as a standard, for which various versions and numerous associated publications are available.

The method of ray tracing is preferably employed for the transfer function of the light conductor. The application of this to light conductors can be derived (among other things) from the previously mentioned document by Bierhoff et al. This is basically a problem of geometric optics whose solution is generally determinable. This solution presents no difficulties because the input rays are defined in a spatial direction and the transfer function, potentially time-dependent, can be defined by the intensity relative to the input intensity emerging at the referenced exit point. With the assistance of the values calculated in this way, as is likewise known from the theory of linear electrical networks, the transfer matrix can be calculated. The determination of the transfer functions with other numerical methods or by measurement is likewise possible.

The allocation of the input/output channels to emission directions and, thus, ray cones, can be relatively well-governed by use of measurement in space. Figure 4a outlines a corresponding arrangement. The transmission diode 10 is charged constantly or pulsed with a pulse source 40; in the latter instance, measurement is carried out during the on and off phases. An optical fiber 41 drawn to a thin tip serves the purpose of measurement, this accepting essentially only optical signals entering axially parallel at its tip and forwarding these to a light detector 42 arranged at the thicker output, from which the output signal is measured.

This optical fiber is moved into various positions in space with a mechanism known from robotics such that the axis of the tip of the optical fiber is directed in the direction opposite the center of the diode and a predetermined spacing from it is set. The spatial distribution can thus be measured and, potentially after combining neighboring rays, defined. The control characteristics in the inside of the model of the diode are derived, as illustrated in Figure 3, by the two arrows between the current through SD and the voltage U1 or, respectively, U2. An alternative to moving the measuring probe is to rotate and tilt the diode in kinematic reversal. When it can be assumed with adequate precision that the beam intensities are axially conically symmetrical, a corresponding rotation of the diode around one axis suffices that proceeds perpendicularly to the symmetry axis of the diode through the essentially punctiform emission spot.

A similar arrangement according to Figure 4b is employed for measuring the properties of the receiver. The measuring device 42 is merely shifted transversely relative to the reception diode 30, i.e., it is rastered in Cartesian coordinates.

However, it is also provided to combine all concentrically placed spatial directions and, thus, to employ a cone sheath. This has the advantage that only relatively few of these channels are needed; these are preferably three channels: one for the cylindrical or conical central ray, the third for all signals having a large angle of incidence and a second for the part lying between them. However, a radial offset of the transmitter or, respectively, receiver can not be taken into consideration with this approach.

For greater clarity, the above description has particularly employed a model with concentrated elements for the optical transmission link. However, every model that can use a simulator can also be utilized for the optical transmission link. These, for example, are models for electrical waveguides or models of delayed current coupling. The model described in the initially cited article is preferably utilized which employs a convolution algebra and may likewise be made available in simulators. Furthermore, the calculation of the transmission properties can also take place using finite element models, even though high computational demands make this approach generally unattractive at the present time.

The above description implicitly assumed that a computer program for the simulation of electrical circuits is employed for the modeling. Of course, the method can also be applied in that the network is simulated by corresponding electrical circuits, usually after transformation into a suitable time and frequency domain. An example of such a simulator is notoriously known and described under the name "Analog Computer".

The above-described method and apparatus are illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.